

Transformation of Soil and Water Properties in Agricultural Lands by Military Activity: Perspectives and Guiding Principles for the Reconstruction of War-Ravaged Agricultural Lands and Waters

Lois Wright Morton¹

ORCID:0000-0003-0197-1039

Farmer and specialty crop grower, Pierpont, Ohio USA Outwash Terrace – Pierpont, Ohio

Professor Emeritus, College of Agriculture and Life Sciences, Department of Criminology and Sociology, Iowa State University, Ames Iowa USA

Solutions from the Land, Lutherville MD USA Board of Directors

DOI: <http://doi.org/10.66659/pd.2026.004>

Published: April 28, 2026

Vol. 2, pp. 43–64.

How to cite: Morton Lois Wright. Transformation of Soil and Water Properties in Agricultural Lands by Military Activity: Perspectives and Guiding Principles for the Reconstruction of War-Ravaged Agricultural Lands and Waters. Pollution and Diseases. 2026; Volume 2: 43–64. DOI: <http://doi.org/10.66659/pd.2026.004>

Abstract

War and conflict contaminate and destroy freshwater and soil resources essential to the production of food and nutrition security, ecosystem health and resilience, farmer livelihoods, and community and national economic wellbeing. The legacies of armed conflict and war on agricultural landscapes are deforestation, degradation of soil physical, chemical and biological properties, geomorphologic transformations, water pollution and destruction of water infrastructure. Farmers and foresters of once productive and profitable agricultural landscapes degraded by military activities are hard-pressed to feed themselves, local and national populations, and have little surplus food and agricultural products for export in support of national economies. Farmers are the foundation of food and nutritional production essential for human development, health and life. It is necessary and urgent that war-ravaged agricultural landscapes be assessed for natural resource damage and contamination, that research and implementation of systems approaches that remediate and reconnect critical soil-water-biological relationships be accelerated, and that coherent and systematic policies and sustained investments at local, regional and national levels be put in place. The reconstruction of these landscapes enable farmers to do what they do best, grow

¹ Corresponding author lwmorton@iastate.edu

food and re-establish their livelihoods and agricultural value chains necessary for food and nutrition security. Twelve overarching Guiding Principles for Reconstruction of War-ravaged Agricultural Lands and Waters are proposed to guide policy, planning and implementation that enable the co-production of food and nutrition security, livelihoods, and natural resource reclamation and resilience.

Keywords: chemical contamination, ecosystem health, farmer livelihoods, food and nutrition security, landmines, soil degradation, war and conflict, war-ravaged agricultural lands, water infrastructure, water pollution.

Key Points

1. Military activity fundamentally transforms soil and water systems, disrupting the ecological basis of food production.
2. War-induced contamination and landscape damage create long-term, often irreversible threats to food and nutrition security.
3. Agricultural productivity depends on restoring soil–water–biological relationships, not just repairing infrastructure.
4. Farmers are central actors in reconstruction and must be integrated into science, policy, and implementation.
5. Effective recovery requires system-level approaches combining remediation, governance, innovation, and long-term investment.

Introduction

Famine begins when soil is degraded, fertility declines and water is polluted and scarce. Plants, trees and animals cannot thrive or survive, and farmers do not have the capacity to produce food for animals and people when their natural resource base is polluted and damaged. War and conflict contaminate and poison streams, rivers, lakes and reservoirs.

Military conflicts alter soil morphological, physical, chemical and biological properties. Most critically, activities of war pollute, disconnect and often destroy soil-water-biological relationships that underlie the productivity of forests, fisheries and croplands and their capacities to produce an abundance of food. Although soil cover damage and water degradation from war and military activities affect a small portion of the total area of the Earth, the damage is transformational and often occurs to highly productive soils that are the source of human food and livelihoods (1,2). Degradation of soil-water-biological relationships can take decades or centuries to restore for agricultural uses and return health to earth systems (1,3,4).

A highly visible impact of wars and conflicts is food crises and increases in food insecurity and malnutrition with the destruction of agricultural land, water and irrigation systems and infrastructure that support food production and distribution (3), (5,6). Damage to agricultural lands can occur from soil compaction of heavy military vehicles, tanks and artillery, and destruction of vegetation which can lead to increased soil erosion and reduced soil fertility (7). Soil morphological properties are altered by

the removal and mixing of soil horizons in the construction of military defenses—ditches, trenches, ramparts, and tunnels (8,9). Exploded shells and bombs create shell holes and craters that change the soil profile substantially mixing O, A, B and C profiles with rock and parent materials (10,11). Chemical pollution to water and soil occurs inadvertently from fuel spills, explosives and other hazardous materials, residues from shrapnel and heavy metals; and purposeful use of organophosphorus nerve agents, radioactive elements and dioxins from contaminated herbicides (1,12). The most common radioactive source on a modern battlefield is depleted uranium (DU), also referred to in the past as Q-metal, depletalloy or D-38 which is uranium with a lower content of the fissile isotope U than natural uranium (13). Conflict generates large amounts of military waste, toxic and hazardous materials, rubble from destroyed buildings, and careless waste management practices that increase risks of toxicity to air, water and soil (7).

War and conflict degrade pasturelands, disrupt seasonal planting, cultivation and harvest activities and displace farm workers in areas of conflict. The resulting crop loss, reduced agricultural productivity, malnourished animals in poor health and loss in farmer income compound the scarcity of local food supplies and affect national and global food and nutritional insecurity (3,7). The basic premise of this paper is that 1) war and conflicts are destructive to agricultural lands and the soil-water-biological relationships necessary for food and nutrition production that enable food security and rural livelihoods; 2) farmers², foresters, fishers, ranchers and all those who work the land and waters are essential to the production of abundant food and nutrition for human development, health and life; and 3) reconstruction and remediation of war-ravaged agricultural lands require urgent responses and systems approaches that reconnect critical soil-water-biological relationships to ensure agricultural, food and nutritional productivity and occupational and food safety. Twelve overarching principles are proposed to guide policy, planning and implementation for reclaiming and reconstructing war-ravaged agricultural lands and enable the co-production of food and nutrition security, livelihoods, and natural resource reclamation and resilience.

RESULTS

Transformation of soil and water resources by military activity

Destruction of agricultural lands by conflict and war is not a new human phenomenon. Folklore claims the Assyrians, Hittites, Hebrews, and Romans spread salt on conquered lands as a ceremonial curse on future crops and enemy cities (14). Early military defensive earthworks were built on flat plain watersheds (often the highest quality agricultural lands) as barriers against invasion. Some of the most devastating activities of war have been the clear-cutting of trees for military uses and civilian

² The term “farmers” encompasses farmers, ranchers, foresters, pastoralists, orchardists, fisherfolk, aquaculturists and all those who are guardians and stewards of working agricultural landscapes. Working landscapes are agricultural croplands, grasslands, orchards and forests, vineyards, fisheries, and other lands and waters that are managed for livelihoods and the production of food and nutrition, fiber, energy, and ecosystem services.

refugees for fuel and housing. The loss of vegetation and soil cover accelerates soil erosion, loss of soil fertility and agricultural productivity decline.

Deforestation in the Mesopotamia, Fertile Crescent, and Sinai Peninsula area has transformed fertile lands into desert landscapes (15). Plant botanists, Moldenke and Moldenke (1952) observed the historical narratives of this region, commonly regarded the location of Garden of Eden, described as the “land of milk and honey”. Ancient Biblical writings report the abundant productivity of Negev and Canaan agricultural lands “...they cut off a branch bearing a single cluster of grapes. Two of them carried it on a pole between them, along with some pomegranates and figs...the land to which you sent us...it does flow with milk and honey! Here is its fruit.” (Nu 13:23; 27) (15). Today, Negev and Canaan are barren lands with famous old cities covered deep with shifting sand, broken and weathered olive presses, “*mute testimony to the bountiful prosperity man once enjoyed from the then rich soil and flourishing agriculture*” (15). Archaeologists and other scientists attribute the barrenness of the exposed eroded land and loss of fertile topsoil from the cutting down of natural forests by natives and “*successive hordes of invaders into Palestine, Syria and Transjordan from 705-681 BC*” (15).

War-ravaged agricultural land and water

The “successive hordes” of war are still with us and continue to contaminate, degrade and destroy forests, agricultural lands and waters with devastating effects on food and nutrition security and rural livelihoods. Explosions of arsenic shells during World War I (1914-1918) around Verdun (France) resulted in heavy contamination of forest soils with arsenic and heavy metals (11). The upper 20 cm soil layers were found to contain high concentrations of copper (16877 mg/kg), lead (26398 mg/kg), arsenic (175907 mg/kg), and zinc (133237 mg/kg) (16). During the Viet Nam War (1965-1972) over 3.2 million liters (468,008 kg As) of the arsenic based herbicide, Agent Blue were sprayed on rice paddies and mangrove forests in the Mekong Delta and Central Highlands killing crops and elevating As levels in water used for agriculture and drinking (17,18).

Soil science research across conflicts from the last seven decades reveals consistent patterns of extensive hazardous military artifacts left behind once hostilities cease. These include widespread deposition of hazardous materials such as shrapnel, shell fragments, unexploded ordnance, and heavy metals including Cr, Sb, As, Cd, Cu, Hg, Ni, and Zn (11). Soil compaction caused by military vehicles and troop movement, particularly under wet conditions, can persist for years despite natural freeze–thaw processes. This leads to reduced infiltration, altered hydrological dynamics, and increased erosion. Mechanical disturbance also destroys soil structure, mixes horizons, removes vegetation, and accelerates land degradation processes (7).

Population displacement and temporary settlements increase pressure on local natural resources, often resulting in deforestation and contamination of soil and groundwater. While the full impact of current conflicts on soil morphology remains insufficiently studied, available evidence indicates extensive environmental

disruption, including bomb craters, trenches, debris fields, and damaged infrastructure (7,8,10,11).

Viet Nam has a long history of numerous wars, foreign occupations, and most recently the Second Indochina War (aka the Viet Nam War 1965-1972) which defoliated rain forests and ancient wetland mangroves and left behind contaminated soil, sediment hotspots, and increased levels of arsenic in water supplies (1,17,18). The legacy of human misery caused by the application of herbicides such as Agent Purple and Agent Orange contaminated with unknown amounts of dioxin TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin) and Agent Blue, the arsenic-based herbicide, sprayed over the jungles, rice fields, and hamlets of Viet Nam still haunt us today (1,19). More than 1.6 million ha of land in southern Viet Nam were sprayed with dioxin contaminated herbicides; and 45% of these ha received four or more spray flight missions. Dioxins are endocrine disrupters and can induce cardiovascular disease, growth and developmental defects, diabetes, hormonal dysfunctions and disruptions, certain cancers, and chloracne (12). Vietnamese farmers, especially young pregnant women whose occupations as farmers involve daily contact with soil and sediments where dioxin TCDD persists in the environment may be at high risk of dioxin accumulation from dermal exposure and bioaccumulation via diet (2).

Reports of wars, conflicts, malnutrition and famine fill the media news feeds daily. The border war between Ethiopia and Eritrea (1998-2000) in the Horn of Africa was fought in a region with a long history of drought-related famine and weak agricultural productivity (20). Engineered land reform, rural cooperatives, state farm and resettlement plans failed to transform agriculture (1974-1991) and left a legacy of failed rural institutions unable to ensure land security for smallholders and their capacity to produce sufficient food for rural and urban populations (20). The web of interactions between years of conflict, drought, loss of access to arable land and pastures, changes in farming systems and herding strategies as well as diversion of resources to the war effort led to the displacement of over one million people from agricultural lands. Deprived of land and livelihoods farmers, especially small holders, were unable to produce food resulting in high rates of chronic under-nourishment in Ethiopia (44%) and Eritrea (58%) (20).

More recently, Russia's large scale military operation in Ukraine (2022 to current) has contaminated the Dnieper River and other watersheds, destroyed water treatment plants, supply systems and sewage units and damaged marine environments with disposal of chemical and biological weapons (21). Shebanin et al. (22) identify Ukrainian soil degradation from military operations ranging from intense bombing, explosion, use of chemicals, contamination with radionuclides, heavy metals, pesticides, oil and oil products especially increasing nitrate concentration in soil contaminated with diesel fuel. A decade of conflict in Syria has destroyed agricultural and food production, leaving a once self-sufficient food producing nation under persistent threat of food insecurity with about 60% of the population estimated in 2021 to be food insecure (23).

Somalia over the past three decades has experienced recurrent civil conflicts, prolonged droughts, food shortages, malnutrition and famines (6). Civil war and changing

climatic conditions have displaced farming communities, weakened traditional seed systems, disrupted local crop diversity and deeply damaged the country's animal and crop production systems. There is an urgent need to rebuild agricultural capacity to support sustainable low-input farming systems and provide households with affordable protein (6). The protracted twenty-year Afghanistan War caused serious direct damage to farmland, normal farm production activities and significant damage to the environment (24). War affected the timing of agricultural planting, shifts in cropping systems from wheat to increase in higher value poppy crops (for drugs marketed through warlords and shadow governments) and most critically a food security crisis with 98% of the people not having enough to eat and wear (24).

The damage of war to productive agricultural soils and waters and the specter of famine hovers not only over the war-torn lands where conflict occurs but reverberates across regions and countries that depend on food imports. The Russian-Ukrainian war illustrates the exacerbated food crisis and nutritional insecurity of regions and countries (e.g. Lebanon, Sudan, Yemen, Sub-Sahara Africa,) who have limited domestic agricultural production, political and social instabilities, lack reliable grain reserves and depend on functioning agri-food systems of other countries for food imports (25,26). A 2019 map (Figure 1) of Ukrainian agricultural exports (January-May) from Business Ukraine magazine illustrates the reach of Ukrainian farmers and their products prior to the 2022 Russian-Ukrainian War. China, India, Egypt, Turkey, and countries of the European Union were major importers of Ukrainian corn, sunflower oil, wheat, soybean, oil cake, poultry and meat (27).

The Ukraine agricultural sector, one of the world's top wheat and grain exporters and a vital source of commodities for the international food system, has been significantly affected by the Russian invasion (28). According to the Kyiv School of Economics, the Ukraine agricultural sector has lost nearly \$82 billion since the beginning of the war (29). The National Scientific Center Institute of Agricultural Economics estimates that agri-food products exported were 57% of all Ukraine total exports in the first six months of 2025 (30). Agriculture in Ukraine has been a major source of economic stability during martial law and an important source of global humanitarian food aid. Small farms and those operating near the war front line are at high risk of losing production hectares and yield/ha due to military activities and limited infrastructure to support storage, transport and input and output markets (29).

Global Market Analysis Feb 2026 of Ukrainian oilseeds and grains production land area and yields compared 2023/24 with projected 2025/26 (31). They show a decrease in hectares planted and yields in oilseeds, with sunflower seed dropping from 6.40 M ha to 5.6 M ha planted and yield drop from 2.42 MT/ha to 1.88 MT/ha and rapeseed from 1.6 M ha to 1.4 M ha planted and yields dropping from 2.97 MT/ha to 2.57 MT/ha. Wheat acreage increased during this period from 5.01 M ha to 5.5 M ha, but yields dropped from 4.59 MT/ha to 4.18 MT/ha and corn yields dropped from 7.74 MT/ha to 6.9 MT/ha (31). The expansion of the war zone and slow pace of demining battlefields makes cultivation of land difficult and unsafe. Any major expansion of cultivated

areas to increase metric tons produced is unlikely. The Ukrainian Accounting Chamber has concluded that full land clearance of mines could take several decades (32).



Figure 1. Ukrainian Agricultural Exports in January-May 2019. Ukraine Feeds the World: Agricultural exports up 21.4% . Ministry of Agrarian Policy and Food of Ukraine (27).

Food and nutrition security require farmers and productive agricultural land

Wars and violent conflicts are key drivers of current food crises (3,33). Further, landmines and explosive remnants of war are persistent threats to lives and food security post conflict (34). Over 99 million people in 23 countries were affected by conflict-driven food crises in 2020, many which were highly dependent on in-country agriculture for food generation (3). More than 39 million people in the Middle East and Asia were affected by conflict-driven food crises with Syria in 2021 having over 12.4 million people food insecure (3,23). Figure 2 shows 67 countries and territories with an estimated 60 million people exposed to the explosive residuals of war in 2024. Travel on rural roads and access to farmlands and grazing areas in these countries is especially dangerous with rural populations disproportionately at risk from landmine maiming and death as well as food insecurity (34). Food import-dependent countries in Africa and Asia are especially vulnerable to hunger and malnutrition due to changing climatic conditions, water scarcity, poor quality soils and non/low-functioning agricultural production and distribution systems with internal violence and conflicts exacerbating food and nutrition sufficiency (5,6,20,26). World Food Program 2026

projections estimate a 21% increase in extreme hunger in West and Central Africa, a 17% increase in East and Southern African and a 24% rise in Asia (33).

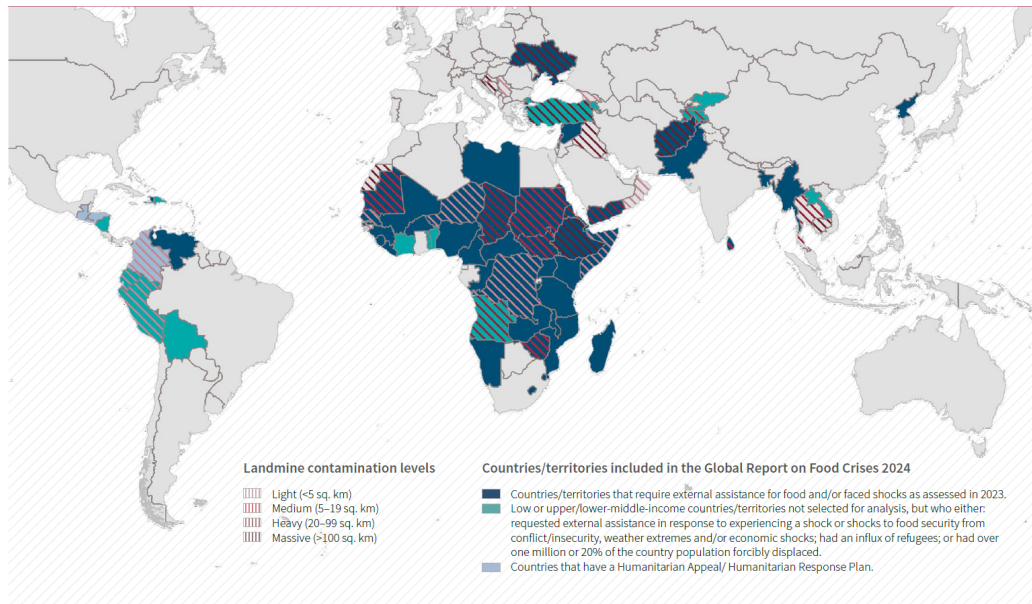


Figure 2. Food insecurity and landmine contamination levels. Sources: The Monitor. 2024. Dynamic Map. In: Landmine and Cluster Munition Monitor. <https://the-monitor.org/dynamic-map> Food Security Information Network and Global Network against Food Crises. 2024. Global Report on Food Crises 2024. Rome. www.fsinplatform.org/grfc2024 (34).

Global hunger reached a record 349 million people in 2022 when the war in Ukraine began and its productive systems of agricultural, water infrastructure, and ports began to be destroyed by land mines, bombs, tanks, missiles and military activities (25,33). A 2026 World Food Program report released in March estimated the total number of people facing acute levels of hunger around the world could reach record numbers if the Middle East conflict escalates and continues to destabilize local and global economies. War and conflict disruptions in oil and energy supplies have cascading effects on farmers' access to fuel (at an affordable price) needed to power tractors and equipment, pump ground water and irrigation systems. The WFP estimates that 318 million people are food insecure and an additional 45 million people could experience acute food insecurity or worse if the 2026 conflict continues (33).

Food and nutrition security

Food security is the ready availability of nutritious and safe food and the assured ability to obtain it through normal sources (35). “*Malnutrition refers to deficiencies, excesses or imbalances in a person intake of energy and/or nutrients together with impaired utilization of nutrients by the body*” (36). Food insecurity and malnutrition are known sources of disease, poor health, stunted mental and physiological development. A great deal of research measures household food insecurity and malnutrition in areas of poverty and war-torn countries and post-war conditions with explanations of causality ranging from gender inequality, poverty, education, and other social-economic factors (36).

A gap in the food security and malnutrition literature is theorizing the relationships among the “conditions” of soil, water, and the natural resource base, the farmers that co-produce food and agricultural products and ecological system conditions, and the agri-food value chain that connects on farm production to food insecure households. Explanations of food insecurity of farming households in war-torn regions are often attributed to weather shocks, climatic conditions and lack of surplus products from animal and crop production systems (36). This is part of the story, but what is missing are the conditions of the environment, the soil and water degradation from military and war related activities that are sources of farm production instability, low productivity, and loss of/disruptions in agri-food production and distribution systems (5).

War-ravaged agricultural landscapes have “conditions” that can limit and prevent the production of safe, healthy, abundant food supplies. For example, how can Ukraine continue to be agriculturally productive under the stress of war conditions? Ukraine has vast quantities of highly fertile, productive black “chernozem” soil (28). It has over 63,000 rivers and 1137 reservoirs used for navigation, agriculture, and public water supply (21). Mines, bomb craters, contamination with heavy metals, soil erosion accelerated by war activities, and loss of land to an invading country is steadily reducing the areas of land available to be cultivated and its productive quality. Although the front-line varies from day to day, about 19% of Ukraine’s territory (~114,000 km²) including Crimea and parts of Donetsk, Kharkiv, Kherson, Luhansk, Mykolaiv, and Zaporizhzhia as of 2025 July were under Russian control (21). Agricultural productivity is also reduced by the pollution and destruction of water infrastructure. The “condition” of these lands and waters to continue to produce safe agricultural products is unknown.

Research on food insecurity, malnutrition, and household coping strategies under wartime conditions that focus only on household social-economic characteristics to explain food insecurity causality is insufficient. While this information is useful in determining humanitarian food aid and policies that address individual level food problems, there is a need for proposing and testing structural and multi-level theories (35). War and conflict exposed agricultural lands, the condition of these lands to be productive, types of military activities and impacts on soil and water resources and farmer capacities to produce food and nutrition and agricultural products under these conditions are critical variables. Multi-level theories are needed that link individual farmer level resources and behaviors to regional, national and global conditions to better parse out these relationships. The remediation of war-ravaged individual farmland and water resources, farmer knowledge and skills for responding to degraded natural and built farm resources, reconstruction resources and strategies, access to and willingness to adopt affordable tools and technologies of food production are all factors that can affect farm productivity post-conflict. Reconstruction happens one hectare at a time, one field, one farm, one watershed until in aggregate entire regions of agricultural lands within a country have increased capacity to produce national food and nutrition self-sufficiency.

Structural variables might include the extent to which local civil society supports their farmers and the reclamation of agricultural resources and return to productivity.

Other structural variables are functionality of local storage, processing, transport, and distribution infrastructure and the flows of agricultural inputs and output markets. Currently, there are structural theories and models of food insecurity and war focused on economic flows, export markets, tariffs and quotas that limit food and agricultural product exports with impacts on farmers' incomes and government export revenues. However, the natural resource base is often treated as an externality that is not accounted for, theorized, measured, and modeled. It is essential to monitor, assess and measure the condition and value of the natural resource base to the individual farmer and to the larger watershed and the nation. The properties of soil, water and biological abundance and diversity, their "conditions" in the agricultural landscape (peacetime, in situ war, and post-conflict) and productive capacities need to be measured and monitored. Identification of the impacts of military actions and the transformations to soil and water properties is necessary (7,21). so as to develop strategies, approaches and technologies to ameliorate, neutralize, and/or remediate the contamination of these resources (34).

Reconstruction of war-ravaged agricultural lands and waters

While there are no quick fixes to remediate, rebuild and reconstruct war-ravaged agricultural landscapes, there is a need for both immediate short-term responses and longer-term system approaches to reclaiming soil and water resources for agricultural and ecological productivity. Decontamination and remediation of soils, including land mine and unexploded ordnance removal, soil detoxification, biological, chemical and physical treatments are necessary to restore soil functions and safe access to ag lands (37). Waterborne pollutants must be removed and functional water infrastructure restored. Farmers have key roles and responsibilities in the reconstruction of war-ravaged agricultural lands and waters, in safeguarding local and global food and nutrition security and ensuring rural livelihoods. Farmers and their representative organizations are important partners in the assessment, design and implementation of reconstructing and regenerating local lands and watersheds that have been exploited and degraded by conflict and war.

Goals to reduce and eliminate famine and create food and nutrition secure communities and nations means investments in the underlying goal of an abundant and nutritious food supply available to all. Research on returning war-ravaged agricultural lands and their ecological systems to health and productivity needs to become a high national and global priority. Farmers are important partners in helping scientists develop research agendas and experimenting with new approaches and technologies. Just as critical for land and water remediation is the need for strong institutional support, collaboration among agricultural organizations, environmentalists, "ordinary" citizens and their governments, and public and private financing. To accomplish this, accelerated science-based knowledge and decision making in conjunction with farmer and indigenous innovation are needed. Further, farmers need access to a "solutions toolbox" that encompasses all available tools, technologies, innovations, scientific, technical and traditional approaches appropriate to geographies, ecosystems and watersheds, cultures and a wide variety of agricultural/forestry systems and scales.

Reconnecting farmers to the land

As the landscape is being demined and decontaminated, the work of reconstruction and making the land productive begins. This means reconnecting farmers to the land, returning displaced farming communities, assessing what they need to be successful and giving them the knowledge and tools to restore and regenerate their soil and rebuild household food and nutritional security. Soil scientists’ recommendations for restoring war damaged landscapes to agricultural uses begin with systematic, field-based assessments and diagnostics of the physical, chemical, and biological conditions of soil and water resources. On the ground sampling in conjunction with satellite imagery can provide the assessments needed to propose a variety of geographical, climatical, and culturally appropriate remediations that scientists and farmers can use to begin to make the land productive.

Established regeneration practices for improving soil, water and biological relationships (Table 1) include the use of cover crops, residue management, intercropping, extended and diversified crop rotations, crop-livestock systems, integrated pest management, re-forestation, perennial and wetland systems, and headwaters and small stream protection (4,38,39,40,41).

Principle	Practices	Benefits
Minimize soil and vegetation disturbance	Notil, reduced tillage rebuild wetlands, plant/maintain forests and grasslands	Reduce runoff and soil erosion, carbon storage
Maximize continuous living roots	Extended crop rotations, intercropping, forests and grasslands	Enhance infiltration, water and carbon storage; improve nutrient movement; promote microbiome activity
Maximize soil and vegetation cover in cultivated and perennial systems	Cover crops, residue management, intercropping, plant/maintain wetland plants, forests, and grasslands	Reduce evaporation and erosion, reduce storm runoff and floodwaters, store carbon, increase microbial activity
Maximize plant and microbial biodiversity	Diversified rotations, organic amendments, integrated pest management	Improve resilience, nutrient cycling, carbon capture
Protect headwaters, small streams, and wetlands	Riparian buffers, reduce/eliminate riparian grazing, restore stream-wetland complexes, vegetated waterways, manage drainage water, bank stabilization, sediment storage areas to decontaminate water	Improve biogeochemical and biological functions, increase water quality, filter and store contaminants, physical and biological processing/removal of contaminants, slow water flows and storm runoff

Table 1. Soil-Water-Biological Relationship Principles (4,38,39,40,41).

Rehabilitation of small stream, ephemeral and intermittent networks and re-establishment of stream wetland complexes are central to restoring water ecosystems functionality. Restoration of contaminated and polluted waters involve slowing flow rates and retaining waters in flood plains, step-pool systems and off-channel storage reservoirs so contaminants are adsorbed to fine sediments and settle from suspension (41). These sediment storage areas of concentrated heavy metals and pollutants enable biological processing and uptake or dredging as necessary (41). These practices in conjunction with phytoremediation, chemical reclamation, reclamation and application of organic fertilizers such phosphate rock, phosphorus and potash fertilizers are needed to make past agricultural lands productive again over time (4,22).

One of the key environmental problems in prolonged war is the degradation of soil by military operations accompanied by intense bombing and use of chemicals that affect soil quality and fertility (22). Optimal technologies for soil restoration post-war conflict are not yet well developed. Construction of ramparts, trenches, and tunnels mix soil horizons with parent material and change morphological properties. Soil building processes on these sites decades after bombing and chemical warfare show re-vegetation in places and resumed accumulation and decomposition of organic matter with microbial action-earthworms, solubilizing and biosurfactant bacterial communities (42). Practices that increase organic matter can increase native microbial activities. For example, the utilization of biochar to remediate soil contamination has shown a significant impact on the biodegradation, leaching and sorption/desorption of organic toxic contaminants (43). Post-Viet Nam War research on dioxin-contaminated soils has isolated biosurfactant producing native bacteria from dioxin-contaminated soils and evaluated their biodegradation capacity to the chemical dibenzofuran (42). To enhance the bio-accessibility, bioavailability, and dissolution of dioxin in soil, scientists are finding the use of biosurfactant producing-bacteria can reduce the oil-water interfacial tension, dissolve hydrophobic dioxins, and distribute them into surfactant micelles (42). There is a need for more laboratory and field experiments to accelerate bioremediation technologies that can break down toxic materials that contaminate soil and water.

Richards found that the uncertainties of war in West Africa affected farmers' decisions about which varieties of rice to plant (5). Although they had available a "superior" rice variety selected for limited tillering and high productivity when grown in densely planted fields treated with fertilizer, farmers in Liberia, Guinea and Sierra Leone preferred to plant an ancient African Rice (*Oryza glaberrima*) variety. This ancient variety has aggressive tillering, grows on poor soils, doesn't need much fertilizer and thrives in weedy fields making it well suited to farming when local violence interrupts their input supply chain and prevents farmers from working their fields daily. Subsequent farmer participation in plant breeding trials on the native African Rice produced a portfolio of new varieties that were better suited to their soil types and low-input conditions with higher yields. Farmer involvement in developing the genetics that better suited their farming conditions increased their willingness to plant these new varieties with higher yields.

Like West Africa, recurrent civil conflict and prolonged droughts in arid and semi-arid Somalia, have disrupted local crop and livestock systems and weakened traditional seed and animal genetics (6). Agricultural faculty from universities in Somalia and United Kingdom interviewed 150 Somalian farmers to assess the current status of cowpea production, their primary affordable protein. The goal was to identify seed breeding priorities including cultivars that are productive in low-input farming systems for the three ecological regions of Somalia and establish a core germplasm collection for future breeding programs. These genetic resources and partnerships with farmers have helped improve cowpea diversity with high drought tolerance and pest and disease resistance (6). In 2013 the African Orphan Crops Consortium identified 101 African crops that are the cultural and nutritional heritage and backbone of the pan-African food system (44). They are training African plant scientists to breed these native crops for improved nutrition, higher yields, water and nutrient use efficiency, pest and disease resistance and climatic resilience. Plants and animals must adapt to many different kinds of ecological niches, address a range of society purposes, and enable the farmer to adapt and produce food and a livelihood in conflict-prone and war-ravaged landscapes (5). Affordable and adaptable genetics suited to local cultures and conditions, developed in collaboration with scientists, local and indigenous farmers are an essential component of the reconstruction of agriculture in war-torn places.

The solution toolbox

The farmer “solution toolbox” has been expanding exponentially over the last few years. Smart farming technologies, digital agriculture, precision agriculture tools and data-driven efficiency analyses are becoming central to research and innovation efforts (45). Cross-disciplinary and multi-institutional research combines agriculture, engineering, computer science, data science, environmental science, geography, economic, sociology and other sciences to develop and test theories, decision support systems and modelling innovations. The momentum to develop new agricultural technologies, artificial intelligence applications, bioremediation, and soil regeneration approaches in agriculture is growing. With continued investment technologies that regenerate and improve soil fertility, biodiversity and water quality are of high value in remediation of agricultural lands contaminated by military activities. One challenge will be their accessibility and affordability to all types and scales of farm operations striving to recover, remediate and reconstruct farm soil and watersheds post-conflict.

David Speidel, U.S. Army in Iraq, Foreign Agricultural Service, observes, “*The solutions toolbox developed by scientists to recover overused, eroded or improperly managed soils has been refined with experience. However, the damage to a soil’s productivity and fertility from battlefield weapons, with heavy metals, remnant complex chemicals such as petroleum and dioxin compounds, and even radioactive material from depleted uranium shells adds a new dimension of complexity to the toolbox. The transportation and accumulation of these pollutants on the landscape must be understood to better reconstruct these battlefield damaged cropland fields*” (13). Speidel offers an example of how mitigation of these pollutants and reconstruction of chernozem soils might play out in a Ukraine battlefield landscape. He writes,

In a perfect world the mine fields are mapped and the engagement areas recorded with the munitions used. In reality, inaccurate records are likely what reconstruction teams advising farmers should expect. Many such records would have been lost, damaged or never made. This would compound the difficulty of the first step: identification and recording of the battlefield areas. Next, would-be correlation of how the heavy metals and other hazardous compounds could attach to the chernozem soil's organic matter and react to its base soil chemistry. Third step would be to follow the pollutants potential water erosion travel in drainage ways to streams, access into ground water or accumulation in sediment deposits. During the summer season when moisture conditions of chernozem soils are driest, dust and silt movement from wind erosion will occur. Wind erosion is less intuitive compared to water erosion which results in stream sandbars, muck in potholes, or the silt bars along floodway stream banks. The windborne piles of silt or sand along fence lines, tree lines, around farmsteads are created from these wind barriers which enables the accumulation of airborne clays and silt or the saltation of heavier silts and sands carrying potential contaminants piled up in new locations.

Recovering Ukraine's productive chernozem soils from battlefield damage will be more than just burying the dead and picking up a few pieces of metal as if a natural storm had blown through. These grasslands-developed soils will range from level with potholes to undulating landscapes of stream bisected rolling hills with sloping windward grades matched by less steep leeward slopes. The high organic matter (OM) soils, nearly reaching the OM levels of a peat soil in the potholes and high sediment loads on the steeper slopes will be a challenge. The OM will secure the heavy metals accumulating in the potholes and the sediment on the floodplains will be another potential hotspot of containments (13).

The hydrological profile of chernozem soils in agricultural landscapes with three zones with different soil moisture dynamics explains the impact of military contaminate translocation and implications for how to best manage these soils in reconstruction efforts. The upper half meter of the soil profile is characterized by an unstable actively changing water regime, the middle part corresponding with the carbonate horizon is dry in all seasons and the lowest part of the profile is always wetter (46). Thus, the patterns of soil-water relationships are not random but follow set patterns that are a function of how soils are formed, the properties they acquire and give clues as to how they will respond to military activities and decontamination efforts. Where potential hot spots are found and new crops cannot be yet planted, the use of cover crops even if flown in can avoid mines or fill in for the absence of farmers and will protect the soil from blowing the contaminants to new locations. Further, ensuring plant roots are in the soil will encourage soil folia and fauna growth and improve hydrology by stimulating microbial and earthworm castings.

FAO has played an institutional role in providing humanitarian action to revitalize agricultural lands and strengthen food security in areas where land mines and explosive remnants of war have degraded soil conditions and disrupted the soil ecosystem (34). They estimate around 139,000 km² of agricultural land in Ukraine has been impacted by explosive hazards and chemical contamination with effects on yields and food safety. Applying its expertise in agricultural assessments, soil and water sciences, land restoration and best farming practices, FAO prioritizes 1) demining efforts based on agricultural potential and needs, 2) investigation, quantifying, and mitigating chemical contamination; and 3) safely reintegrating lands into agriculture use and sustainable food systems (34).

One of FAO's major contributions as technical convener of the National Working Group on Soil Pollution, led by the Ministry of Economy, Agriculture and Environment is methodological standardization (34). This has entailed developing a national soil sampling protocol for Ukraine to ensure that all future assessments, whether conducted by government, laboratories or partners produce comparable and reliable data. The protocol defines sampling design, multi-increment sample approaches, depth and spatial representativeness as well as quality assurance and health and safety procedures. The soil sampling process is explicitly linked to determining whether land is safe for cultivation, requires remediation or needs risk management measures. FAO's approach integrates soil science, geospatial data analysis and modelling, and adapted agricultural extension to support farmers affected by artillery shelling and explosive hazards. Within its programme supporting vulnerable communities, covering a land-bank of approximately 15,000 hectares, FAO combines field-based soil contamination assessments with spatial prioritization tools to guide safe land use and recovery. This is complemented by tailored extension support to farmers to manage residual risks, restore soil health.

Investments in post-conflict restoration projects and programs are critical in linking science, indigenous knowledge, human and economic resources to rural farm communities. It is important to involve farmers and a range of cropping systems, and farm sizes (large, medium and small) as well as vulnerable groups (women, indigenous peoples, youth) in these projects (5,47). Collaborative platforms provide practical lessons on war-ravaged agricultural landscape remediation and strategies and methods for restoration management of soil and freshwater resources. They also provide investment frameworks that allow farmers, farmer organizations and agricultural value chains to rebuild their food and agricultural systems, develop public–private partnerships, risk-sharing instruments, and aggregation models that improve access to finance.

Guiding principles for the reconstruction of war-ravaged agricultural lands and waters

Restoration of agricultural and forestry soil resources and freshwater functionality is essential to enable farmers who manage, lease and own agricultural lands to safely re-engage and accelerate the production of food and nutrition and their livelihoods. Twelve overarching Guiding Principles for Reconstruction of War-ravaged

Agricultural Lands and Waters are proposed to guide policy, planning and implementation to enable the co-production of food and nutrition security, livelihoods, and natural resource reclamation and resilience:

1. *Farmers are the foundation of local, regional and global food and nutritional security* (7). Farmers and their representative organizations must be fully recognized as core design and implementing partners in reconstruction of agricultural lands and water resources degraded and contaminated by war and conflicts.

2. *There are no quick fixes to reconstruct war-ravaged agricultural lands and waters.* Remediation, rebuilding and reconstruction of agricultural landscapes will require immediate, short-term gap responses and longer-term system approaches that reconnect critical soil-water-biological relationships to ensure agricultural, food and nutritional productivity and occupational and food safety (47).

3. *Decontamination and remediation of soil resources, including land mine and unexploded ordnance removal* to restore safe access and soil functions for agricultural and food production uses will require a combination of physical, physicochemical and biological/ biochemical assessments and restoration approaches that entail immediate, short-term actions and longer-term systematic persistent assessment, monitoring, remediation and reconstruction methods at multiple scales (farm, local watershed, and regional) (7,37).

4. *Removal of waterborne pollutants and re-establishing functional water infrastructure* for human and agricultural uses must be a high local, regional and national priority. This includes assessments, restoration of community and regional water supply systems, treatment plants and sewerage units; and public and private investments in water resources that enable food production, storage and distribution systems to function effectively and safely (21).

5. *Rivers, headwaters, wetlands, reservoirs, and riparian assessment, monitoring, remediation and restoration* are essential to ensure adequate farm level access to crop and animal water supplies, irrigation, and well-systems for safe food production and drinking water (21,48).

6. *Farmers must have a land tenure system* that provides legal and customary arrangements, land ownership and lease rights and responsibilities that are fair and equitable and ensure affordable access to land, water, and the natural resource base.

7. *Research on the decontamination, reconstruction, and restoration of war-ravaged agricultural landscapes* must become a high national and global priority with strong institutional support and public and private funding. Science-based knowledge and decision making, in conjunction with farmer and indigenous innovation are central to effective adoption of agricultural technologies, innovations and practices that can remediate, reconstruct and restore biodiversity, ecosystem wellbeing and food and nutrition security (47).

8. *Farmers are key partners in the development of research agendas, experimentation and testing of new technologies* and approaches that remediate, improve

and enable soil, water, and natural resource capacities to produce safe abundant nutritious food supplies and agricultural products (2,5,47).

9. *Farmer and landowner skills, knowledge and capacities* to restore and manage war-ravaged agricultural landscapes must be accelerated, strengthened and increased through 1) environmental education, training and tools; 2) applications of satellite imagery, remote sensing and other technologies, data and information analyses; 3) access to grants and finance to restore, rebuild the farm enterprise; 4) facilitated peer to peer knowledge exchanges and partnerships with scientists and technical personnel (2,21,47).

10. *Farmers need access to a “solutions toolbox” that encompasses all available tools, technologies, innovations, scientific, technical and traditional approaches* appropriate to geographies, ecosystems and watersheds, cultures and a wide variety of agricultural/forestry systems and scales without predetermining or limiting technologies, production type or design components that they may use to achieve decontamination and reconstruction of their farm and watershed level goals (37,47).

11. *Post-conflict restoration projects and programs should involve farmers and a range of farm sizes (large, medium and small) and vulnerable groups (women, indigenous peoples, youth);* and provide practical lessons on agricultural landscape remediation, strategies and methods for restoration management of soil and freshwater resources, and investment frameworks that allow farmers, farmer organizations and agricultural value chains to rebuild their food and agricultural systems and develop public–private partnerships, risk-sharing instruments, and aggregation models that improve access to finance. Proven strategies and successful remediation models that can be replicated and scaled up or down need to be daylighted and catalogued as part of the “solutions toolbox” (2,48,49).

12. War and conflict too frequently spill over and transcend geo-political boundaries. *Transboundary cooperation and multi-lateral integrated management* of water, forests, grasslands and other natural resources should be implemented as appropriate (48,50,51).

Conclusion

Wars and conflicts are destructive to agricultural lands and waters necessary for food and nutrition security and rural livelihoods. Around the world where most of these conflicts occur, war exacts a heavy toll, which is too often paid by women, children, and indigenous people. Women in many of these war-ravaged lands play important roles in agriculture, especially as small holders in local communities. The protection of all farmers including vulnerable groups and their capacities to create food and nutrition secure households means they must have access to land, water, finance, and science-based knowledge and technologies to support their decision-making.

Local community social and “civic” structures where citizens engage each other informally and formally to address food and nutritional problems is necessary if long

term solutions to increasing food access and reducing food insecurity are to be achieved (35). Further, rehabilitation of agri-food value chains and markets (storage, processing, transport, insurance, input and output markets) will be essential so that restored and reclaimed agricultural lands and waters actually translate into viable agri-food production systems, food and nutrition security and livelihoods. Reconstruction and remediation of war-ravaged agricultural lands require farmers' active participation in developing urgent responses and systems approaches that ensure agricultural, food and nutritional productivity and occupational and food safety. Waiting is not an option. We must find ways and resources to begin to heal our lands and waters. The best way to protect and enlarge our agricultural food system and ensure food and nutritional security is to build relationships of peace among peoples and nations.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

The author thanks the farmer–scientist leadership of Solutions from the Land (SfL) for their review, edits, and endorsement of the Guiding Principles for Reconstruction of War-ravaged Agricultural Lands and Waters.

Special thanks are extended to FAO leadership for their contributions to humanitarian mine removal efforts, their work on soil pollution related to war and conflict, and their engagement with scientists and farmers in restoring the productive capacity of war-affected agricultural landscapes.

The views expressed in this paper are those of the author and do not necessarily reflect the perspectives of SfL or FAO.

Funding

This research received no external funding.

Data Availability Statement

No new data were created or analyzed in this study.

References

1. Olson, KR, Morton, LW. Long-term fate of Agent Orange and dioxin TCDD contaminated soils and sediments in Vietnam Hotspots. *Open Journal of Soil Sci.* 2019; 9: 1-34. <https://doi.org/10.4236/ojss.2019.91001>
2. Meaza, H, Ghebreyohannes, T, Nyssen, J, Tesfamariam, Z, Demissie, B, Poesen, J, Gerehiwot, M, Weldmichel, T.G., Deckers, S, Gidey, DG, Vanmaercke, M. Managing the environmental impacts of war: what can be learned from conflict-vulnerable communities. *Science of the Total Environment.* 2024; 927171974. <https://doi.org/10.1016/j.iswcr.2024.11.004>

3. Kemmerling, B, Schetter, C, Wirkus, L. The logics of war and food (in)security. *Global Food Security*. 2022; 33. <https://doi.org/10.1016/j.gfs.2022.100634>
4. Hatfield, JL, Racetter, KA, Birge, HE, Wecker, D J, Wyatt, BM, Wacha, KM, Lal, R. Soil health and hydrological process: Keys to sustainable agriculture. *Advances in Agronomy*. 2026.
5. Richards, P. The history and future of African Ricer: Food security and survival in a West African war zone. *Afrika Spectrum* 2006; 41:1:7-93.
6. Warsame, A, Isse, YA, Sh Abdi, AM. Production status, breeding priorities and genetic resources of cowpea in post-civil war Somalia. *Food and Energy Security*. 2026; 15:e70181 <https://doi.org/10.1002/fes3.70181>
7. Filho, W, Fedoruk, M, Eustachio, JHPP, Splodytel, A., Smaliychuk, A., Szykowska, Jozwik, M I. The environment as the first victim: the impacts of the war on the preservation areas in Ukraine. *Journal of Environmental Management*. 2024; 364. <https://doi.org/10.1016/j.jenvman.2024.121399>
8. Olson, KR, Morton, LW. Why were the soil tunnels of Cu Chi and Iron Triangle in Vietnam so resilient? *Open Journal of Soil Sci*. 2017; 7:34-51. http://file.scirp.org/pdf/OJSS_2017020911121143.pdf
9. Olson, KR, Speidel, DR. Review and analysis: Successful use of soil tunnels in Medieval and modern warfare and smuggling. *Open Journal of Soil Sci*. 2020; 10:194-215. <https://doi.org/10.4236/ojss.2020.105010>
10. Pereira, P, Basic, F, Bogunovic, I, Barcelo, D. Russian-Ukrainian war impacts the total environment. *Science of the Total Environment*. 2022. <https://doi.org/10.1016/j.ecoenv.2022.114322>
11. Williams, OH, Rintoul-Hynes, NLJ . Legacy of war: Pedogenesis divergence and heavy metal contamination on the WW front line a century after battle. *Eur J Soil Sci*. 2022; 73:e13297 <https://doi.org/10.1111/3jss.13297>
12. Morton, LW, Culbertson, C. Persistence of dioxin TCDD in Southern Vietnam soil and water environments and maternal exposure pathways with potential consequences on congenital heart disease prevalence in Vietnam. *Open Journal of Soil Science*. 2022; 12:119-150. <https://doi.org/10.4236/ojss.2022.124005>
13. Speidel, D. R. Personal communication. U.S. Army Iraq, Mosul and Balad, Iraq; Foreign Agricultural Service, Baqubah and Mahmudiyah, Iraq; Foreign Agricultural Service, Washington DC USA. March 7, 2026.
14. Stevens, ST. A legend of the destruction of Carthage. *Classical Philology*. 1988;32(1):39-41. <https://doi:10.1086/367078>
15. Moldenke, HN, Moldenke, AL. *Plants of the Bible*. Chronica Botanica Co, Waltham, Mass; Dover Publications, Mineola, NY. 1952, reprint 1986.
16. Bausinger, T, Bonnaire, E, Preuss, J. Exposure assessment of a burning ground for chemical ammunition on the Great War battlefields of Verdun. *Sci. Total Environ*. 2007; 382, 259–271. <https://doi.org/10.1016/j.scitotenv.2007.04.029>
17. Olson, KR, and Cihacek, L. Agent Blue spraying in the Mekong Delta during the Vietnam War: Fate of the arsenic based herbicide weapon used to destroy rice crop

- and mangrove forests. *Open Journal of Soil Sci.* 2022; 12:253-294.
<https://doi.org/10.4236/ojss.2022.127012>
18. Olson, KR. Agent Blue: A secret military and environmental chemical weapon used for food denial in South Vietnam during the Vietnam Civil War (1962-1965). *Open Journal of Soil Sci.* 2023. <https://doi.org/10.4236/ojss.2023.133007>
 19. Speidel, DR, Olson, KR. Review and Analysis: Evaluation of the impacts and consequences of using agricultural herbicides as military chemical weapons in second Indochina War. *Open Journal of Soil Sci.* 2024; 14: 471-498.
<https://doi.org/10.4236/ojss.2024.148025>
 20. White, P. War and food security in Eeritrea and Ethiopia, 1998-2000. Disasters 2005; 29(51): s92–s113. Overseas Development Institute, Published by Blackwell Publishing, 9600 Garsington Road, Oxford, OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.
 21. Manoiu, VM, Costache, MS, Nica, MA. The impact of the Russia-Ukraine War on water resources and infrastructure of Ukraine - A comprehensive review. *MDPI.* 2025; 1-30.
 22. Shebanin, V, Gamayunova, V, Karpenko, M, Babych, O. Restoration of war-damaged soil fertility to ensure sustainable agricultural production, food security and global recognition of Ukraine. *Scientific Horizons.* 2024. 27(6):129-140.
<https://doi:10.48077/scihor6.2024.129>
 23. Ibrahim, K, Bavorova, M, Zhllima, E. Food security and livelihoods in protracted crisis: the experience of rural residents in Syria’s war zone. *Food Security.* 2024; 16:659–673. <https://doi.org/10.1007/s12571-024-01446-z>
 24. Lu, J., G. Li, J. Huang, L. Zhang, J Wang, D. Zhu, and Z. Yalo. Impacts of the 20-year war on crop planting and food security in Afghanistan, *International Journal of Digital Earth,* 2024 17:1, 2344585. <https://doi:10.1080/17538947.2024.2344585>
 25. Al-Saidi, M. Caught off guard and beaten: The Ukraine war and food security in the Middle East. *Frontiers in Nutrition.* 2023; <https://doi.10.3389/fnut.2023.983346>
 26. Boon, EK, Kobliansska, I, Ahenkan, A, Kanton, RAL, Kyrylenko, M.. The dilemmas of agri-food systems and food and nutrition security in Africa: Lessons from the Russo-Ukrainian war. *Geopolitics under Globalization.* 2025; 6(1), 59-70.
[https://doi.org/10.21511/gg.06\(1\).2025.06](https://doi.org/10.21511/gg.06(1).2025.06)
 27. Business Ukraine Magazine. 2019. Post to facebook.com July 3.
<https://www.facebook.com/BusinessUkraineMagazine/>
 28. Feingold, S. Ukraine’s food exports by the numbers. *World Economic Forum.* July 25, 2022, Updated June 3, 2025; Downloaded 3.06.2026. Ukraine’s food exports by the numbers | World Economic Forum
 29. Avramenko, O. Ukraine Agricultural Exports 2024. *Linked In* 6 March 2026. Head of the EU Integration Committee at Ukrainian Agibusiness Club Association (UCAB) on Ukrainian Agri-food exports. 2024; <https://dia.dp.gov.ua/en/ukraine-exported-5-million-tons-of-agricultural-products-in-february-2026/>

30. Ukrainian agricultural exports exceed 11 billion in six months, according to the Committee on Agrarian and Land Policy. 2025, August 5. Verkhovna Rada of Ukraine. <https://www.rada.gov.ua/en/news/News/264685.html>
31. FAS/USDA (Foreign Agricultural Service/United States Department of Agriculture). Global Market Analysis World Selected Countries and Regions. 2023/24 to project 2025/26 Tables 02, Wheat,04 Corn,06 Oats,10, Total Oilseed,11 Soybean,14 Sunflower Seed,15 Rapeseed. February 2026; Downloaded 3.16.2026. Ukraine | USDA Foreign Agricultural Service
32. Obukh, W. From crisis to hope. How Ukrainian agricultural exports are weathering one of their toughest seasons. ZNUA Mirror of the Week. 12 September 2025. Downloaded March 16, 2026 Ukraine's agricultural sector in 2025: what disrupted exports and what farmers are hoping for - <https://zn.ua>
33. WFP (World Food Program USA). WFP projects food insecurity could reach record levels as a result of Middle East escalation. March 17, 2026. Global Hunger Could Reach Record Levels Because of Conflict.
34. FAO (Food and Agriculture Organization of the United Nations). FAO's role in humanitarian mine action. Office of Emergencies and Resilience. 2024; OER-Director@fao.org fao.org/emergencies Rome, Italy CD2750EN/1/11.24 FAO's role in humanitarian mine action.
35. Morton, LW, Bitto, EA, Oakland, MJ, Sand, M. Solving the problems of Iowa food deserts: Food insecurity and civic structure. *Rural Sociology*. 2005; 70(1):94-112.
36. Nkoko, N, Cronje, N, Swanepoel, JW. Factors associated with food security among small-holder farming households in Lesotho. *Agricultural & Food Security*. 2024; 13:3. <https://doi.org/10.1186/s40066-023-00454-0>
37. Santos, M, Rebola, S, Evtuguin, DV. Soil remediation: current approaches and emerging bio-based trends. *Soil Systems*. MDPI. 2025;9: 35. <https://doi.org/10.3390/soilsystems9020035>
38. Hatfield, JL, Sauer, T, eds. *Soil Management: Building a Stable Base for Agriculture*. American Society of Agronomy and Soil Science of America. Madison, WI USA; 2011.
39. Olson, KR, Ebelhar, SA, Lang, JM. Effects of 24 years of tillage on SOC and crop productivity. Special edition. *Soil Management for Sustainable Agriculture*. 2013; 1:1-10. <http://dx.doi.org/10.1155/2013/617504>
40. Olson, KR, Ebelhar, SA, Lang, JM. Long-term effects of cover crops on crop yields, soil organic carbon stocks and sequestration. *Open Journal of Soil Science*. 2014; 4(8): 284-292. <http://doi.org/10.4236/ojss.2014.48030>
41. Wohl, E, Lane, SN, Wilcox, AC. The science and practice of river restoration. *Water Resources Res.*, American Geophysical Union. 2015; 51, 5974-5997. <https://doi.org/10.1002/2014WRO16874>
42. Nguyen, KN, Chau, TAT, Nguyen,TKO, Le, TX, Morton, LW, Demyan, MS, Huu, TT, Dang, HG, Duong, MV, Vu, NT, Huseyin, BT.. Isolation of biosurfactant producing bacteria from dioxin-contaminated soil and their biodegradation capacity to dibenzofuran. *Biocatalysis & Agricultural Biotechnology*. 2025. <https://doi.org/10.1016/j.bcab.2025.103490>

43. Haider, FU, Wang, X, Zulfiqar, U, Farooq, M, Hussain, S, Mehmood, T, Naveed, M, Li, Y, Liqun, C, Saeed, Q, Ahmad, I, Mustafa, A. Biochar application for remediation of organic toxic pollutants in contaminated soils: An update. *Ecotoxicology and Environmental Safety*. 2022; 248:114322.
<https://doi.org/10.1016/j.ecoenv.2022.114322>
44. African Orphan Crops Consortium. African Orphan Crops Consortium – Healthy Africa through nutritious, diverse and local food crops.
<https://africanorphanecrops.org>
45. SfL (Solutions from the Land):Morton, LW, Yoder, F, Shea, E, Anderson, J, Bridgeforth, K, Doyle, B, Gaesser, R, Kawamura, AG, Kent, , Kimble, M, LaCross, B, Moller, A, Shapiro, H, Ulibarri, V. Solutions from the Land Data Policy Guidance on Farm Data: Strengthening Collection, Analysis and Use of Agriculture and Food System Data for Sustainable Development Attainment (SDGs). Solutions from the Land. Lutherville, MD USA. 2023.
46. Bulgakov, V, Holovach, I, Demydenko, A, Trokhaniak, O. Study of moisture conditions of chernozem in the left-bank forest-steppe of Ukraine. *International Scientific Journal Mechanization in Agriculture & Conserving of Resources*. 2024; WEB ISSN 2603-3712; PRINT ISSN 2603-3704.
<https://stumejournals.com/am/2024/4/135.full.pdf>
47. SfL (Solutions from the Land), Morton, LW, Hatfield, J, Kawamura, AG, Kimble, M, Lovejoy, T, O’Toole, P, Shapiro, H, Vats, V, Williams, B, Yoder, F. 21st Century Renaissance: Solutions from the Land. Solutions from the Land. Lutherville, MD USA. 2021. <https://www.solutionsfromtheland.org/>
48. UNEP (United Nations Environmental Program). Freshwater Priorities 2022-2025. To implement UNEP’s medium-term strategy. Inter-Divisional Water Group. 2022. Freshwater Strategic Priorities 2022-2025 | UNEP - UN Environment Programme
49. UNFCCC (United Nations Framework Convention on Climate Change) Farmers Constituency. Informal consultation submitted on the 2026 Mitigation Work Programme dialogue, intervention statement. March 2026.
50. Morton, LW, Girgis, C, Shea, E. Cross-Boundary Collaboration in Large Working Landscape Management: Anticipating and Planning for Climate Disruption and Continuous Change in US West Grassland-Forest Working Landscapes. Solutions from the Land, Lutherville MD USA. 2024. Headwaters of the Colorado - Solutions from the Land
51. UNECE (United Nations Economic Commission for Europe).The Water Convention and Protocol on Water and Health. Convention on the Protection and Use of Transboundary Watercourse and International Lakes . Intergovernmental platform to facilitate cooperation on sustainable use of transboundary water resources. 2026. The Water Convention and the Protocol on Water and Health | UNECE